THE USE OF SYNTHETIC JP-8 FUELS IN MILITARY ENGINES

TARDEC

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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  - Heat Release Analysis
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Introduction

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- **Study the impact of alternative jet fuels on military engines**
  - Evaluate multi-cylinder production engines
    - Obtain information on large scale issues such as performance, component wear and possible failure modes
  - Use research engine to support production engine results
    - Use data to quantify the differences seen in the multi-cylinder testing
    - Allows for precise control over intake conditions and injection event
    - Obtain detailed engine measurements such as in cylinder pressure, temperatures and injection data not possible to obtain on the production engines

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- **1988 introduced the single fuel forward initiative**
  - Mandates the use of a single fuel (JP-8) for Army vehicles

- **Push for "green" technologies**

- **2009 ASTM International specification for jet fuel changed**
  - Allows up to a 50-50 % blend by volume of JP-8 and Fischer Tropsch synthetic paraffinic kerosene JP-8 (FT SPK JP-8)

- **Need to know vehicle impact before field use**

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Engine Testing

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- **Two multi-cylinder production engines tested**
  - HMMWV GEP 6.5L
  - Bradley FIV Cummins VTA903
- **Single cylinder research diesel engine**
  - AVL 521

Engine Parameter	AVL	GEP 6.5	Cummins 903
Injection System	IRI BETA	Pump Line Nozzle (PLN)	Step timing control, Pressure Time (PT)
Peak Injection Pressure [bar]	1600	700	1300
Nozzle Geometry [mm]	7 x 0.191	single hole	7 x 0.190
Bore x Stroke [mm]	120 x 120	103 x 97	140 x 120
Peak Firing Pressure [bar]	200	-	-
Compression Ratio	16	20.2	14.5
Displacement [L]	1.4	6.5	14.8
Swirl Number	Variable	NA	-
Operating Speeds	800-3000	1500-3400	800-2900
Cylinders	1	8	8
Boost System	Shop air	Turbocharger	Turbocharger
Rated Power		190 hp @3400 rpm	600 @ 2600
Rated Torque		375 ft-lbs @ 1800 rpm	1200 @ 2600

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- **400 hour NATO test**
  - Performed with both the Cummins 903 and GEP 6.5
  - Performance benchmarked on DF-2 then evaluated using JP-8 or the 50-50 blend
    - New engines used for each fuel
  - Intake air set at 77°F
  - Fuel temperature 86°F
  - Data recorded at 0, 100, 200, 300 and 400 hours of testing
  - Full load data recorded at 100%, 75% and 60% of the rated speed and max torque speed
  - Part load conditions ran but not studied here
  - Cummins 903 ran elevated temperatures but the results are not included
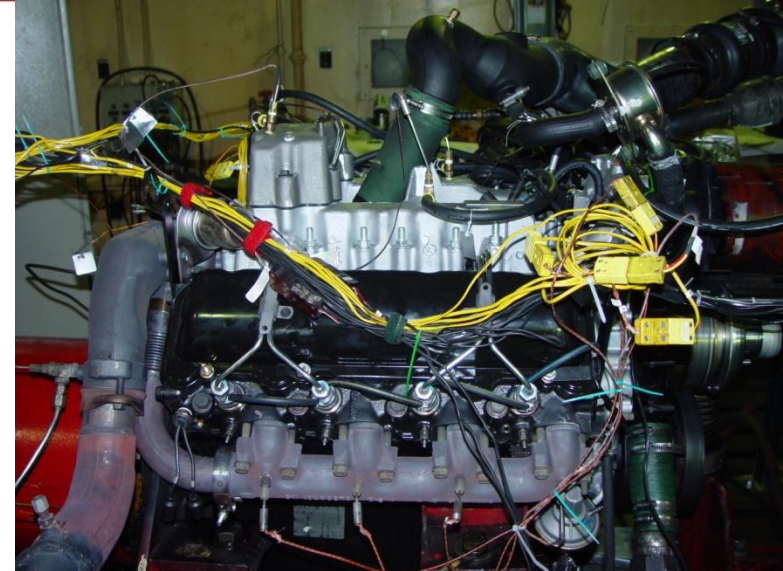
GEP 6.5 L engine

Cummins 903 engine

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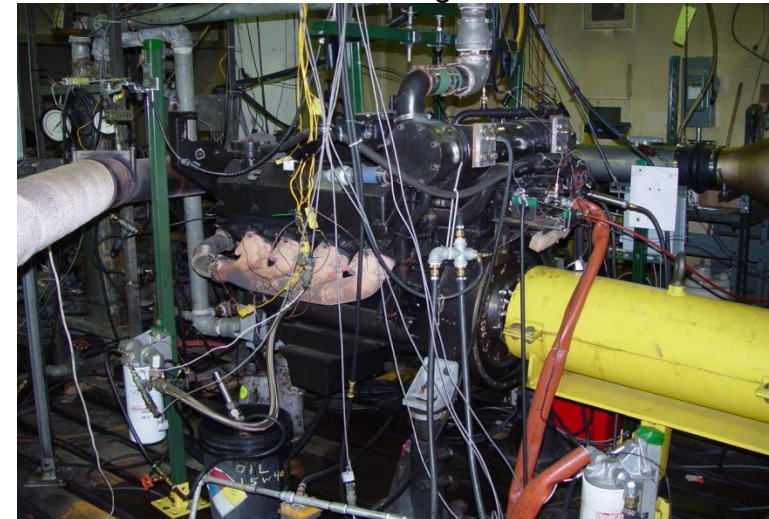
- **AVL 521 test strategy**
    - Calibrate engine for best fuel consumption using DF2
    - Use only a single injection event
   - Operate full load conditions at six engine speeds
    - Hold fueling and intake air constant
    - Allow air fuel ratio (A/F ratio) and torque to vary
    - Document performance
    - Perform advanced combustion calculations

AVL 521 Single Cylinder

Speed	Intake Pressure	Exhaust Pressure	Oil Rail Pressure	Intake Temperature	Pulse Width	Injection Timing bTDC
[RPM]	[psi]	[psi]	[psi]	[F]	[ms]	[deg]
1250	16.5	9.7	3500	145	4	19
1400	27	18.4	4500	177	4.2	18.5
1600	26	21	4000	195	4.2	19.35
1800	26.7	26.7	4000	210	3.5	20.25
2000	28.2	29.3	4800	213	3.3	18.8
2200	30	36	4800	213	3.1	21.35

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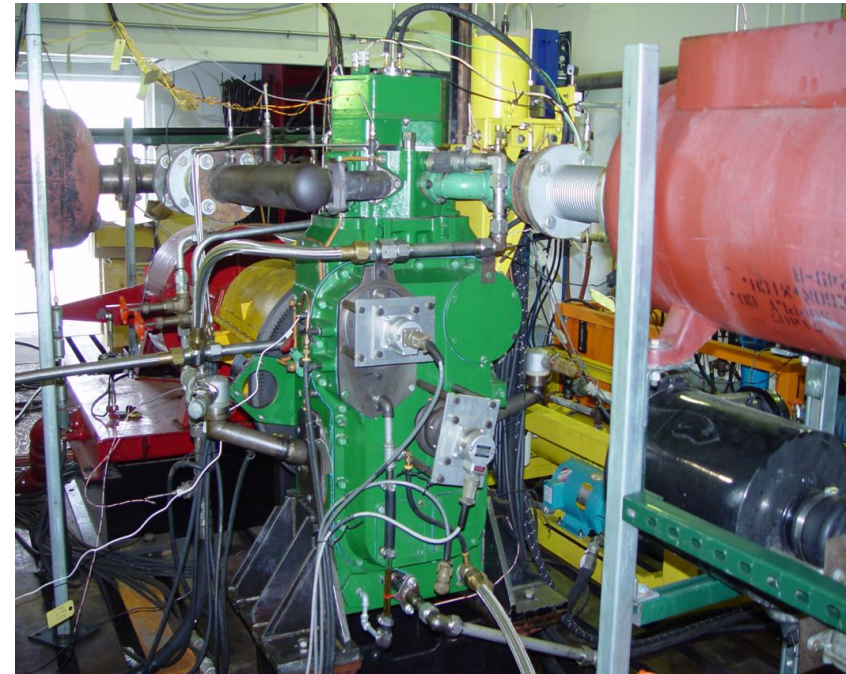
- **Multi-cylinder engine testing**
  - DF-2, JP-8 and 50-50 blend JP-8 and FT SPK JP-8
- **Single Cylinder**
  - DF-2, JP-8, 50-50 blend, Syntroleum 8 (S-8), Sasol FT SPK JP-8 (Sasol)
- **Fuel analysis performed to determine properties**
  - Large cetane number, density and boiling point differences

Fuel	Cetane Number	Density	Viscosity	Viscosity	T90 Boiling Point	Lower Heating Value	Aromatics % Volume	Sulfur Content
	[]	[kg/L] @ 15 C	[mm^2/s] 40	[mm^2/s] -20	[C]	[MJ/kg]	%	[ppm]
DF2	42.8	0.8655	2.688		317.1	42.6	45.74	390
JP8	44.9	0.8026	1.39	4.96	234.4	43.4	14.69	23
50/50	47.3	0.7923	1.2925	4.397	232.1	43.4	14.05	30
S8	62.4	0.7554	1.2862	4.42	248	44.1	0	1.6
Sasol JP8	25.2	0.7612		3.4775	205.3	44	0.89	-

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Experimental Results

- **Multi-cylinder engine tests**
  - Loss of torque for both fuels compared to DF-2
  - No component failures or excessive wear

Engine	Engine Speed [RPM]	Torque with DF-2 [ft-lbs]	Torque with JP-8 [ft-lbs]	Torque with 50-50 blend [ft-lbs]	% Decrease for JP8 []	% Decrease for 50-50 []
903	2600	1264.67	1209.67	1197.33	4.36	5.32
903	2400	1300.67	1253.67	1242.67	3.59	4.43
903	2200	1294.33	1254.67	1238.67	3.04	4.30
903	1800	1236.00	1208.33	1189.33	2.24	3.77
903	1600	1164.67	1142.00	1119.67	1.93	3.82
HMMWV	1800	381.76	357.02	336.66	14.18	19.08
HMMWV	2100	376.39	346.32	330.62	8.00	12.17
HMMWV	2400	362.90	333.40	316.31	8.13	12.83
HMMWV	2700	341.82	317.35	300.71	7.16	12.03
HMMWV	3000	325.72	303.07	286.22	6.95	12.13
HMMWV	3200	315.14	292.05	275.75	7.33	12.51
HMMWV	3400	301.80	281.75	263.93	6.64	12.56

- **Single cylinder engine test**
  - Reduction in torque for all fuels compared to DF-2

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2
DF2	128.67	0.00	159.43	0.00	146.45	0.00
JP8	118.19	8.14	162.28	-1.79	141.12	3.64
50-50	115.62	10.14	149.77	6.06	146.79	-0.23
S8	116.06	9.80	154.71	2.96	144.10	1.60
Sasol	123.73	3.84	137.93	13.49	140.90	3.79
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2	Torque [ft-lbs]	% Decrease WRT DF2
DF2	120.10	0.00	116.73	0.00	108.40	0.00
JP8	112.93	5.97	112.01	4.04	106.64	1.62
50-50	114.55	4.62	113.88	2.44	105.46	2.71
S8	111.32	7.31	122.55	-4.99	99.41	8.29
Sasol	118.19	1.59	116.14	0.51	103.14	4.85

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- **Some power loss can be explained by the reduced energy content of the alternative fuels**
  - $E_f = \rho_f \times LHV$
  - E_f = Energy input of the fuel
  - ρ_f = density of the fuel
  - LHV = lower heating value of the fuel

- **DF-2 has the highest energy input**
  - Means if injection parameters are held constant it is expected that DF-2 would create more power

Fuel	Energy Input [J/m^3]	Ratio to DF2
DF2	36870.3	1.00
JP8	34832.84	0.94
50/50	34385.82	0.93
S8	33304.32	0.90
GTL	34177.5	0.93
Sasol	33492.8	0.91

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- **Fuel density**
  - Shown previously can cause a reduction in the energy content
  - Causes a change in fuel consumption
    - Higher density causes a larger quantity of fuel to be injected during the same duration

- **Viscosity**
  - Has a minimal effect on injection and spray parameters

- **Lubricity**
 - Low lubricity can negatively affect the fuel injection pump and injector life

Engine Speed	2600	2600	2400	2400	2200	2200
Fuel	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2
DF2	222.07	1.00	205.23	1.00	187.25	1.00
JP8	209.74	0.94	197.71	0.96	178.77	0.95
50-50	208.01	0.94	194.07	0.95	174.42	0.93
Engine Speed	1800	1800	1600	1600		
Fuel	Fuel Consumption [lb/hr]	Ratio to DF2	Fuel Consumption [lb/hr]	Ratio to DF2		
DF2	149.32	1.00	130.24	1.00		
JP8	145.73	0.98	126.01	0.97		
50-50	142.44	0.95	124.16	0.95		

903 Data ^

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2
DF2	10.67	1.00	14.54	1.00	16.09	1.00
JP8	9.32	0.87	13.43	0.92	14.83	0.92
50-50	8.97	0.84	12.99	0.89	14.86	0.92
S8	8.85	0.83	12.56	0.86	14.40	0.90
GTL	9.52	0.89	13.13	0.90	14.47	0.90
Sasol	8.88	0.83	11.63	0.80	13.67	0.85
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2	Fueling Rate [lbs/hr]	Ratio to DF2
DF2	14.08	1.00	15.69	1.00	16.07	1.00
JP8	12.81	0.91	14.90	0.95	15.04	0.94
50-50	13.03	0.93	14.65	0.93	14.86	0.92
S8	11.93	0.85	14.26	0.91	14.45	0.90
GTL	12.23	0.87	14.34		14.46	0.90
Sasol	12.62	0.90	14.20	0.91	14.73	0.92

AVL Data ^

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- **Cetane number (CN) is the fuel property with the largest effect on ignition and combustion**
  - Ignition delay (ID) is the amount of time it takes for the fuel to ignite
  - High CN result in shorter ID times
    - ➢ Long ID can lead to high pressure rise rates which can damage engines
  - Low CN has poor ignitibility
    - ➢ Would not be able to cold start

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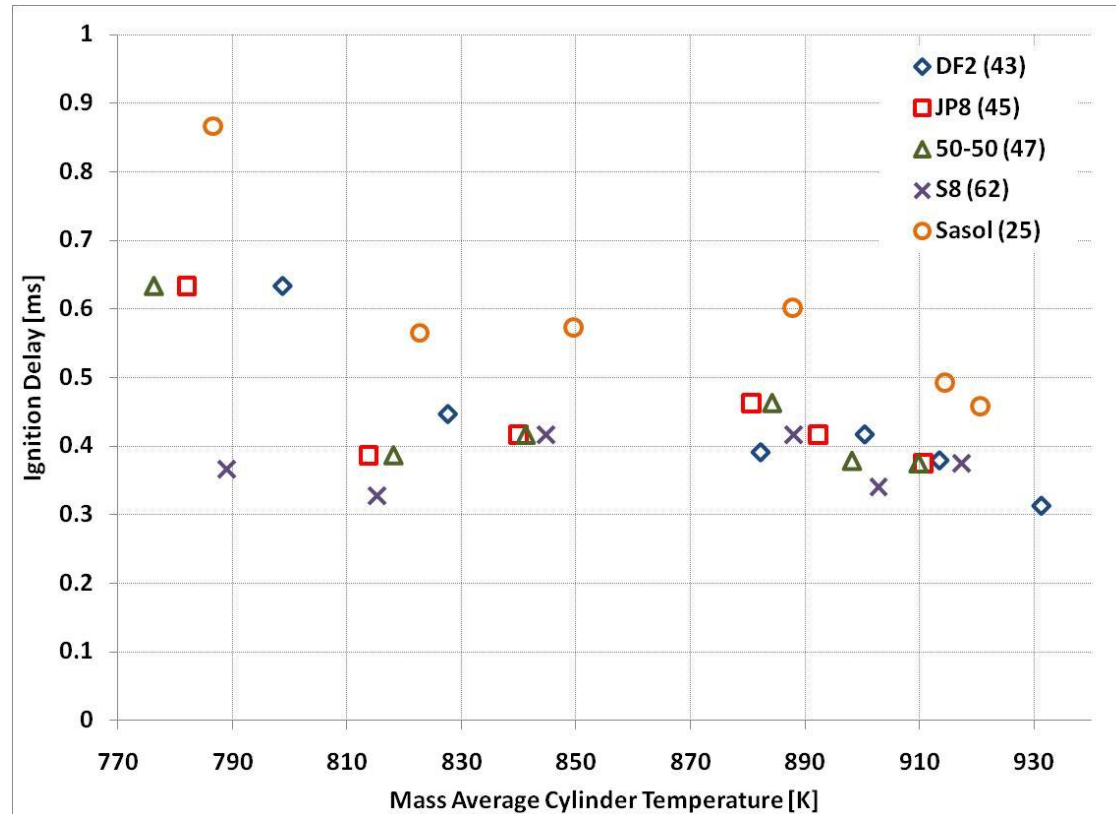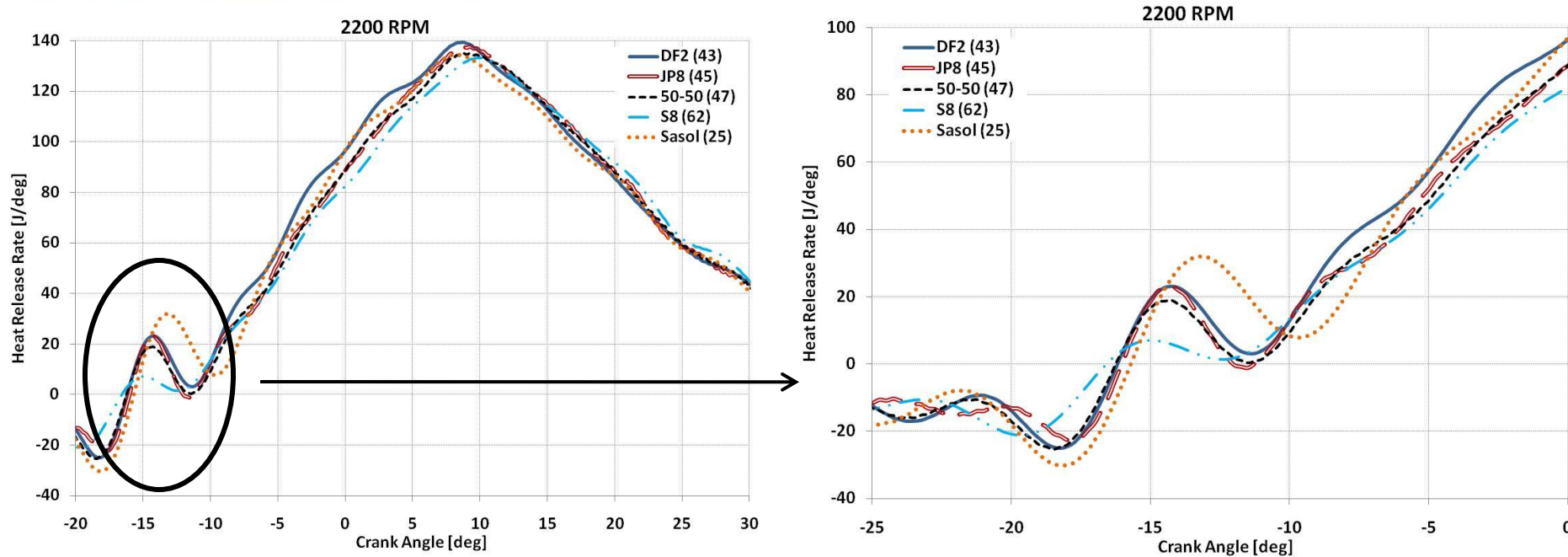
- **Premix region**
  - JP-8 and DF-2 very close
  - 50-50 slightly lower
  - S-8 ignites quick and small premix burn
    - Low pressure rise rate
    - Runs quiet
  - Sasol large premix spike
    - High pressure rise rate

- **Diffusion burn**
  - JP-8 and DF-2 very close
  - 50-50 slightly lower
  - S-8 has lower magnitude peak and peaks later
    - Lower HR results in less power produced
  - Sasol declines quicker

- **Sasol and S-8 variances**
  - S-8 has a high CN and low volatility (T90 = 248 C)
    - Ignites quick
    - Takes more time to evaporate
  - Sasol has low CN and high volatility (T90 = 205 C)
    - Long ignition time but evaporates quick

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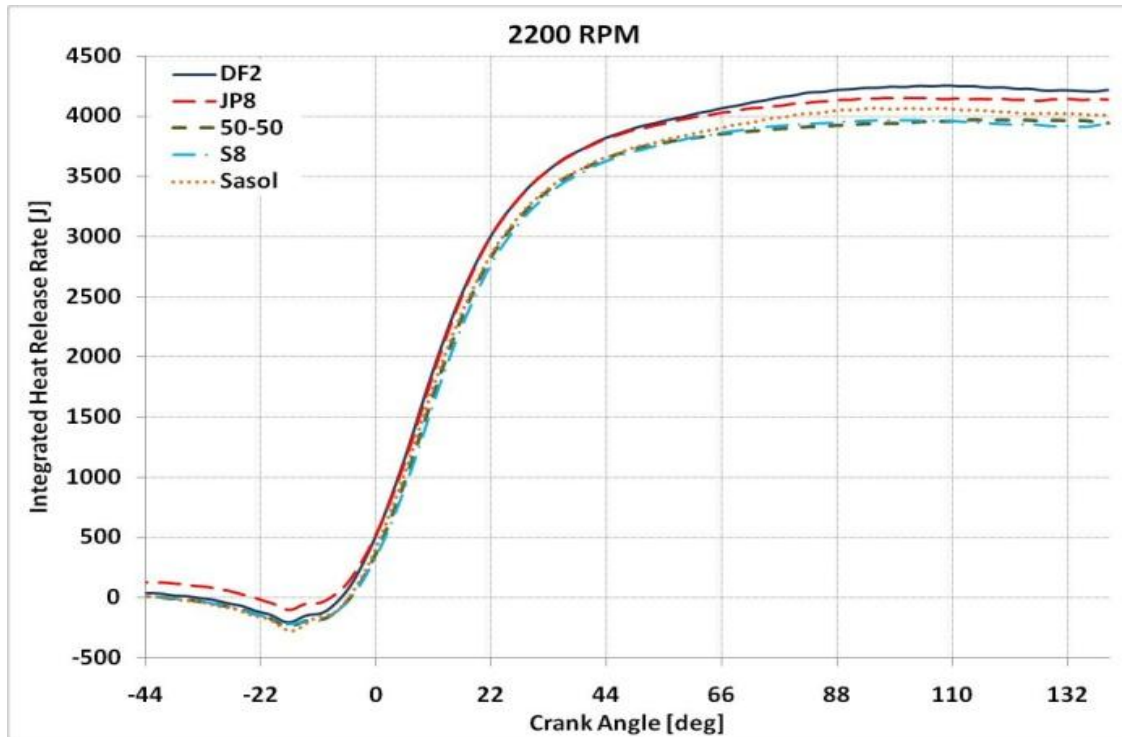
- **Integrated rate of heat release (IRHR) at exhaust valve close (140 ˚ aTDC) gives the total energy released during combustion**
  - Data confirms observations made in torque and fuel energy input
  - S-8 and 50-50 blend very similar explaining lack of clear trend in data

- **Exhaust temperatures affect emission formation, turbocharger performance and the thermal signature of a vehicle**
  - Alternative fuels had lower exhaust temperatures
  - Higher fuel energy input leads to higher IRHR and higher exhaust temperatures
  - Higher fuel consumption leads to higher A/F ratios and higher exhaust temps
  - Variations of combustion phasing seen in the HR profiles will affect the temperatures
  - HMMWV engine has more pronounced differences
    - Due to more pronounced fueling rate changes with this engine

Engine	Engine Speed [RPM]	Exhaust Temperature DF-2 [F]	Exhaust Temperature JP-8 [F]	Exhaust Temperature 50-50 [F]	JP-8 ratio to DF2	50-50 ratio to DF-2
903	2600	1171.90	1158.73	1155.73	0.99	0.99
903	2400	1178.13	1169.70	1167.30	0.99	0.99
903	2200	1200.70	1190.00	1189.73	0.99	0.99
903	1800	1301.37	1287.50	1288.87	0.99	0.99
903	1600	1365.47	1354.30	1350.60	0.99	0.99
HMMWV	1800	1033.68	963.54	930.82	0.93	0.90
HMMWV	2100	1094.94	1002.99	977.67	0.92	0.89
HMMWV	2400	1172.89	1080.44	1046.54	0.92	0.89
HMMWV	2700	1222.37	1141.51	1106.21	0.93	0.90
HMMWV	3000	1303.29	1222.80	1193.50	0.94	0.92
HMMWV	3200	1355.40	1272.72	1235.78	0.94	0.91
HMMWV	3400	1397.15	1320.35	1277.87	0.95	0.91

Engine Speed	1250	1250	1400	1400	1600	1600
Fuel	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2
DF2	1042.11	1.000	1112.94	1.000	1267.08	1.000
JP8	1047.04	1.005	1105.77	0.994	1262.61	0.996
50-50	953.49	0.915	1079.89	0.970	1181.12	0.932
S8	973.13	0.934	1037.91	0.933	1165.6	0.920
Sasol	993.7	0.954	964.88	0.867	1077.65	0.850
Engine Speed	1800	1800	2000	2000	2200	2200
Fuel	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2	Exhaust Temperature [F]	Ratio to DF2
DF2	1073.28	1.000	1087.72	1.000	1001.08	1.000
JP8	1066.76	0.994	1102.39	1.013	980.78	0.980
50-50	1047.64	0.976	1069.24	0.983	970.42	0.969
S8	1005.67	0.937	1054.91	0.970	951.37	0.950
Sasol	1022.37	0.953	1005.25	0.924	940.47	0.939

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Conclusions

- **Production engine tests were completed using the blended fuel with no component failures**
- **Power loss for alternative fuels tested**
  - Could possibly mitigate with timing changes
    - ➢ Not feasible with out knowing precise fuel properties
    - ➢ Not easily performed in a field environment
- **Lack of JP-8 specifications combined with possible low quality synthetic fuels could have disastrous results if unknowingly blended**
  - Low lubricity
  - Low cetane
  - Combustion phasing and spray targeting
- **Desert conditions could result in greater power loss**
- **Part load conditions still have to be investigated**
- **Cold start may be an issue**

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ACKNOWLEDGEMENTS

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